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INCLUSIONS IN ALUMINUM-ALLOY SAND CASTINGS

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BY

R. J. ANDERSON

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CONTENTS.

	Page.
Introduction	1
Purpose of investigation	2
Acknowledgments	2
Method of investigation	2
Experience at foundries	3
Foundry A (sand-casting plant)	3
Foundry B (sand-casting plant)	3
Foundry C (die-casting plant)	4
Foundry D (sand-casting plant)	4
Foundry E (sand-casting plant)	5
Foundry F (sand-casting and die-casting plant)	5
Foundry G (sand-casting plant)	6
Foundry H (sand-casting plant)	6
Kinds and characteristics of hard spots	6
Nonmetallic hard spots	7
Metallic hard spots	8
Causes and factors affecting the occurrence of hard spots	9
Causes of nonmetallic hard spots	9
Causes of metallic hard spots	9
Effect of size of castings	11
Effect of machining and polishing	11
Effect of the method of molding	11
Effect of the method of melting	11
Effect of the quality of the melting stock	13
Effect of the rate of production	13
Experiments in connection with hard spots	13
Foundry experiments	13
Experiment A	14
Experiment B	14
Experiment C	15
Experiment D	15
Experiment E	15
Experiment F	15
Summary of experiments	15
Examination of the rough castings	17
Machine work on the experimental castings	17
Polishing the castings	17
Metallography of the castings	18
Laboratory experiments	18
Iron-pot scale	18
The composition and identification of hard spots	19
Production of hard spots at will	20
Summary and conclusions	20
Methods of preventing hard spots	21
Publications on nonferrous metallurgy	23

TABLES.

Page.

TABLE 1. Summary of foundry experiments 16
2. Chemical composition of iron-pot scale and scrapings from iron pots 19

ILLUSTRATIONS.

Page.

PLATE I. *a*, Piece of brick in gate; *b*, piece of stone in gate; *c*, piece of hard, clayey material in gate; *d*, chunk of crucible in gate 6
II. *a*, Stony hard spot in vacuum-cleaner fan; *b*, inclusions of bits of crucible in vacuum-cleaner fan; *c*, chunk of crucible in polished casting 7
III. *a*, Hard spots in a casting that gave much trouble on machining; *b*, microstructure of one of the small inclusions in *a*; *c*, inclusions in a die casting; *d*, microstructure of the stony spot in *c* 8
IV. *a*, Crystals of $FeAl_3$ in a die casting that polished poorly; *b*, crystals of $FeAl_3$ in unetched section from same sample as *a*; *c*, needle of $FeAl_3$ from same sample as *a*; *d*, feather of $FeAl_3$ (white) embedded in alloy matrix (dark) 9
V. *a*, Iron-pot scale in sand-cast No. 12 alloy; *b*, microstructure of the scale in *a* 10
VI. *a*, Macrostructure of gate, experiment A; *b*, macrostructure of gate, experiment B; *c*, macrostructure of gate, experiment C 18
VII. *a*, Macrostructure of gate, experiment D; *b*, macrostructure of gate, experiment E; *c*, macrostructure of gate, experiment F 19

INCLUSIONS IN ALUMINUM-ALLOY SAND CASTINGS.

By Robert J. Anderson.

INTRODUCTION.

Discussions of inclusions in aluminum alloys have not appeared hitherto in metallurgical literature, although much has been written regarding sonims,[1] slag,[2] and other foreign inclusions[3] in iron and steel. In addition a few scattered papers dealing with foreign inclusions in brass and bronze[4] and other nonferrous metals[5] have appeared. In aluminum-alloy foundry parlance, metallic and nonmetallic inclusions are termed "hard spots," and in aluminum-alloy sand castings and in die castings they are very troublesome. The inclusions differ so widely that the term "hard spots" is only roughly descriptive at best; in fact, the term is exceedingly undesirable, and should not be accepted in the nomenclature of metallography. However, because it has been in common usage for such a long time it will be used in this paper to include all kinds of metallic and nonmetallic inclusions that cause difficulty in polishing and machining aluminum-alloy castings. Another justification for the use of the term is that this paper is published for founders rather than metallographers. Hard spots in aluminum-alloy sand castings are well known to the former, and certain kinds of hard spots are frequently

[1] Hibbard, H. D., The solid nonmetallic impurities in steel—sonims: Proc. Intern. Assoc. Test. Mat., 6th Congress, New York, 1912, part 2, p. 10. The solid nonmetallic impurities in steel (sonims): Trans. Am. Inst. Min. Eng., vol. 41, 1910, pp. 803–822.

[2] Rosenhain, W., Slag-enclosure: Proc. Intern. Assoc. Test. Mat., 6th Congress, New York, 1912, part 2, p. 2.

[3] Arnold, J. O., and Bolsover, G. R., The forms in which sulphides may exist in steel ingots: Jour. Iron and Steel Inst., vol. 89, 1914, pp. 396–403; vol. 91, 1915, pp. 271–274. Comstock, G. F., Alumina in steel: Met. and Chem. Eng., vol. 13, 1915, pp. 891–895; and A method for distinguishing sulphides from oxides in the metallography of steel, Trans. Am. Inst. Min. Eng., vol. 56, 1916–17, pp. 553–560. Sauveur, A., An investigation dealing with the occurrence of alumina inclusions in steel: Met. and Chem. Eng., vol. 15, 1916, pp. 149–151. McCance, A., Inclusions in steel: Jour. West of Scotland Iron and Steel Inst., vol. 24, 1916–17, pp. 55–68; and Nonmetallic inclusions, their constitution and occurrence in steel: Jour. Iron and Steel Inst., vol. 97, 1918, pp. 239–286. Kilby, J. N., Steel ingot defects: Jour. Iron and Steel Inst., vol. 95, 1917, pp. 69–89. Stead, J. E., Note on inclusions in steel and ferrite lines: Jour. Iron and Steel Inst., vol. 97, 1918, pp. 287–292.

[4] Comstock, G. F., Notes on nonmetallic inclusions in bronze and brass: Trans. Am. Inst. of Metals, vol. 12, 1918, pp. 5–10.

[5] Thompson, F. C., On graphite and oxide inclusions in nickel silver: Jour. Inst. Metals, vol. 22, 1919, pp. 327–328.

found in aluminum-base die castings. Ordinarily, hard spots are not noticed during the routine inspection of rough castings in the foundry, but usually come to light during machining. Much difficulty may be experienced when machining aluminum-alloy castings containing hard spots, and their presence may be one of the principal causes of machine-shop scrap, in addition to ruined milling cutters, lathe tools, and drills. Certain kinds of hard spots may be found when gates are being sawed off at the band saw, or on cutting at the sprue cutter, or when chipping and grinding is being done. Furthermore, several kinds of hard spots may be readily detected in the foundry by fracturing the gates; if hard spots are present in the gates, they will normally be present in the castings. Whether or not hard spots are numerous in an aluminum-alloy casting, this defect may be such as to cause much difficulty in machining and, at times, even to prevent the finishing of machine work after it has begun. Milling cutters, turret-lathe tools, drills, and other machine tools can be quickly dulled and rendered unfit for cutting when the cutting edges strike hard spots in a casting. When hard spots are present in aluminum-alloy castings, they slow down machining, cause many castings to be scrapped, involve loss of machine work, reduce production, ruin cutting tools, and irritate machine operators.

PURPOSE OF INVESTIGATION.

Although many representative aluminum-alloy founders by care in practice have been able practically to eliminate hard spots and resulting trouble when aluminum-alloy castings are machined, others still have periodic difficulties because of this defect. A number of foundrymen have suggested at various times that the Bureau of Mines investigate hard spots, put the available information on record, and suggest preventive methods. Such an investigation was undertaken and carried out in connection with the bureau's work on casting losses in aluminum-alloy foundry practice. The present paper is published as a contribution to the literature of aluminum-foundry practice and as a guide to founders in preventing scrap losses from hard spots in castings.

ACKNOWLEDGMENTS.

The writer is indebted to numerous representatives of aluminum-alloy foundries who have kindly supplied data and samples, and particularly to F. Felix, of the Apex Foundry Co., Cleveland, Ohio. The analyses mentioned on page 20 were made by J. H. Capps.

METHOD OF INVESTIGATION.

In conducting the present investigation, a number of aluminum-alloy founders were requested to outline their experience with hard

spots and to submit typical samples of castings containing this defect. The information thus gathered was analyzed, and the samples submitted were examined microscopically. In this way, the experience of representative foundrymen has been made available, and practically all possible kinds of hard spots have been examined. Furthermore, an investigation was made of the actual conditions in a foundry which was in the throes of an epidemic of hard spots for six or eight weeks. In addition, hard spots were produced purposely in sand castings.

EXPERIENCE AT FOUNDRIES.

Founders and foundry metallurgists who, in reply to inquiries, related their experience with hard spots in aluminum-alloy castings have supplied considerable information. Evidently the opinions of founders who have had trouble with hard spots and have been able practically to eliminate this defect should be particularly valuable. Excerpts from replies follow.

FOUNDRY A (SAND-CASTING PLANT).

In regard to hard spots in aluminum-alloy castings, our experience with this trouble is that it usually comes from using remelted aluminum which has been run down from borings, where the iron content has not been eliminated before melting.

Iron chips in aluminum borings will not melt, but they ball-up with aluminum on the outside of each chip and are suspended in the metal. This iron chip or boring (hard spot) oxidizes and becomes very hard after melting once or twice. These hard spots will not segregate, but will be held in suspension throughout the casting in different parts. At least this is our theory of this trouble, because for several years we were bothered very much, and found out that it was due to using remelted aluminum made from aluminum chips containing iron borings. After we stopped using such aluminum, we have had no further trouble.

Another point which we watch very carefully is that there is no core sand left in the castings which we remelt; otherwise, this sand may find its way into the castings and cause small hard spots. The explanations which have been given to us regarding hard spots have been merely suppositions. Hard spots appear and disappear, but we think that they are caused by some foreign substance, which is not originally in the metal itself, as we have never found them in new metal.

FOUNDRY B (SAND-CASTING PLANT).

We have never found hard spots in our aluminum-alloy castings, and a diligent inquiry has failed to disclose any evidence that our machining sections have ever had trouble with this defect. * * * We had, at one time, some trouble with oxide spots in magnalium castings, but have discontinued using this alloy.

FOUNDRY C (DIE-CASTING PLANT).

So-called hard spots are recognized by us as of three distinct classes:

1. Distinct nonmetallic particles resembling particles of sand.
2. Distinct black metallic particles, magnetic, resembling hard iron.
3. Gray amorphous semimetallic particles.

We attributed 1 and 2 above to the adherence of sand and scale to the iron castings used as melting pots, and decided to pickle all iron castings so used. By pickling the castings, as they came from the foundry, in a weak solution of hydrochloric and hydrofluoric acids, at least 90 per cent of our hard spots were eliminated.

Condition 3, however, still exists to a small extent. We have been able to isolate good samples of these gray spots and upon analysis found them to consist of approximately 4 per cent carbon and 96 per cent aluminum, which led us to believe that these hard spots were due to the formation of a carbide of aluminum.

In melting aluminum in a cast-iron pot, the iron dissolves gradually in the aluminum. We are of the opinion that this dissolved iron does not cause any hard spots, since it is dissolved uniformly in the alloy and the hard spots have no direct bearing on the iron content of the aluminum castings as shown by analysis.

It is our belief that as the iron is dissolved, the carbon present is liberated in an active form and combines with the aluminum to form a carbide which collects on the walls of the melting pot and finally finds its way into the castings. Assuming this theory to be correct, the solution would be in the use of a melting pot having the lowest carbon and silicon content. We are proceeding on this theory and expect to try out some steel pots having the lowest possible carbon content.

FOUNDRY D (SAND-CASTING PLANT).

We have seldom found many instances where the machine shop has had contentions that castings were hard in spots. The misuse of the word "hard" is prevalent among machinists. They say that the metal is "hard" when what they really mean is that "it is difficult to machine." Very often the difficulty arising is due to the metal being rather soft, causing subsequent dragging in machining operations. * * * In a few instances, however, we have been unable to determine the cause for the trouble which the machine shop was experiencing. * * * The so-called hard spots disappeared before we could ascertain what they really were.

In many cases we have found the hard spots due to the chemical composition of the alloy used. Magnesium present in small amount, even 0.25 per cent, has caused us difficulty. We found that a tool and a set-up which would machine a straight No. 12 alloy would not work on a No. 12 alloy containing this small amount of magnesium.

Other hard spots that we have run into were small black inclusions in the original virgin aluminum from which we made our casting alloys. * * * The little black spots are hardly more than microscopic in size, and * * * have been explained to us as a formation of carborundum, the carbon and silicon uniting in the electric furnace when the aluminum is manufactured.

* * * The opinion has also been voiced that hard spots would be caused by small percentages of manganese. This does not seem plausible to us.

FOUNDRY E (SAND-CASTING PLANT).

From our experience, hard spots in aluminum castings come from one of two sources:

(1) When aluminum is kept molten in an iron pot or crucible, ladled out in rather small amounts, and additional metal recharged, it wets the sides of the container and forms a small layer of aluminum which soon oxidizes. This builds up in thickness, turning more and more into oxide until there is apt to be a layer of aluminum and oxide mixed adhering to the side of the pot. In ladling out metal, if the ladle scrapes against the side of the pot, small particles of this will break off and get in the molten metal and be poured in the castings. The way to eliminate this is to use an iron scraper and scrape down the sides of the pot at least three or four times daily, and skim off the scrapings, putting them with the regular skimmings to be refined in the ordinary way.

(2) In cleaning up chips and sloppings from the floor, especially where the floors are of concrete or dirt, small particles of concrete or gravel are apt to be swept up. These are charged into the furnaces along with the metal to be melted and on account of the small difference in specific gravity of the aluminum and concrete they become mixed with the metal and are apt to be ladled out and poured into the castings.

By carefully watching the above sources of trouble, we have been able to practically eliminate the question of hard spots which interfere with machining.

FOUNDRY F (SAND-CASTING AND DIE-CASTING PLANT).

Referring to your letter in regard to hard spots, we recognize them to be of two kinds; those due to sand and stone and those due to iron. All hard spots are due to foreign materials since they get in the castings in the foundry and are never found in virgin melting stock.

The first kind of hard spots come from charging such materials as core sand, pieces of brick, and pieces from the cement floors, while the second seem to be due to core wires, nails, iron chips, and drillings. Also, spots due to iron must come from melting in iron pots * * *. When melting in new iron pots, hard spots are rarely found, but they often occur when melting in old pots under certain conditions. In melting this way, a hard brittle iron-aluminum formation occurs which sticks to the sides of the pot; if this is knocked off into the metal, hard spots follow. * * * In stirring metal in an old pot or in ladling, pieces of this hard compound are always knocked off into the metal if the stirrer or ladle hits the sides of the pot.

However, by scraping the pots about three times a day and by being careful not to hit the sides of the pot on ladling or stirring, we have been able to eliminate most spots due to this cause. In scraping the pots, all of the hard compound adhering to the sides must be loosened and removed, and if any is left in, it will cause hard spots. * * *

We also found another kind of hard spots which really ought not to be called hard spots at all; these are sand inclusions and seem to be found always on the cope side of the castings, as in crank cases. We think that they are due to wrong gates or to too fast pouring because the sand from the mold is washed into the surface of the casting. These spots, then, consist simply of sand from the mold washed into the casting by the flowing metal. * * *

FOUNDRY G (SAND-CASTING PLANT).

Our experience with hard spots in aluminum ingots and castings has been quite extensive. A few years ago we endeavored to have an aluminum producer explain these conditions which we found in ingots furnished us.

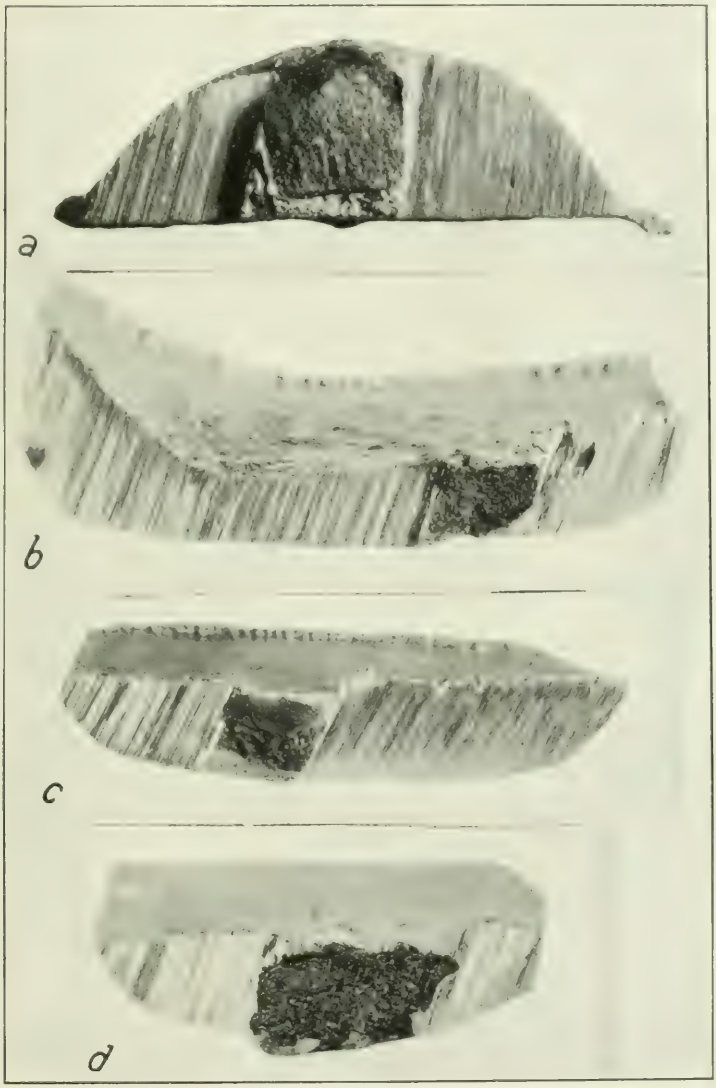
The producer's explanation was to the effect that it was an aluminum oxide which they were unable to overcome, and to the present day we find difficulties, although not so bad. We find, sometimes, in melting that unless we are very careful this difficulty will crop out through carelessness in our foundry. We have discovered that if the iron melting pots are not thoroughly cleaned each day we have this trouble, which we think is caused by the scale from the iron pot alloying with the aluminum in melting.

FOUNDRY H (SAND-CASTING PLANT).

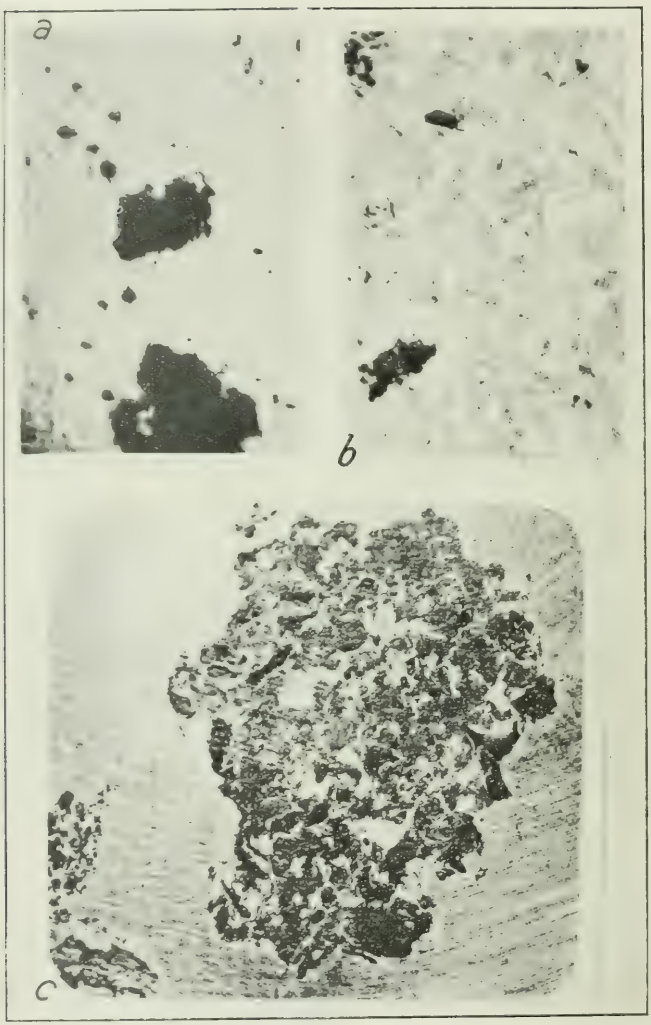
We have never experienced at this plant the troubles referred to, at least in no exaggerated form. The only trouble of this nature which we might mention is where in trying to make use of machine-shop scrap, particles of iron or other foreign materials find their way into the aluminum and give some trouble in machining. It seems to us that this is probably the most likely source of hard spots, for we presume in foundries having a large production, such as automobile crank cases and other parts, the machine-shop scrap is remelted, and there is every opportunity for foreign matter to find its way into the aluminum.

KINDS AND CHARACTERISTICS OF HARD SPOTS.

Various kinds of hard spots in aluminum-alloy castings are recognized by different founders, and it is evident that such inclusions may be classified according to their character. In the same way it is also possible to determine the causes of hard spots and suggest methods for preventing their occurrence. All hard spots may be divided into two classes—nonmetallic hard spots and metallic hard spots. The essential features of each are discussed below.



a, PIECE OF BRICK IN GATE (X 1); *b*, PIECE OF STONE IN GATE (X 2); *c*, PIECE OF HARD CLAYEY MATERIAL IN GATE (X 2); *d*, CHUNK OF CRUCIBLE IN GATE (X 2).



a, STONY HARD SPOT IN VACUUM-CLEANER FAN, UNETCHED, VERTICAL ILLUMINATION (X 7); *b*, INCLUSIONS OF BITS OF CRUCIBLE IN VACUUM-CLEANER FAN, ETCHED NaOH, OBLIQUE ILLUMINATION (X 7); *c*, CHUNK OF CRUCIBLE IN POLISHED CASTING, OBLIQUE ILLUMINATION (X 4.5).

NONMETALLIC HARD SPOTS.

Under this heading are included all such hard, foreign, nonmetallic inclusions as pieces of brick or cement, chunks of crucibles, core sand and molding sand, and hard clay. These materials can not be found in the castings unless they are charged into the melting pots or are allowed to fall into the pouring ladles, and they can not be associated normally with the original melting stock. Nonmetallic hard spots range in size from microscopic particles to chunks one-half inch cube and larger. Occasionally there may be a so-called occurrence of hard spots, as where surface sand is found in a casting, because incorrect gating or rapid pouring or both permitted sand from the mold to be eroded by the stream of metal and carried into the casting. On machining, any surface sand might give trouble and dull the cutting edges of machine tools. Actual examples of this have been observed.

Typical examples of nonmetallic hard spots found in aluminum-alloy castings are shown in Plate I, *a*, *b*, *c*, and *d*; Plate II, *a*, *b*, and *c*; and Plate III, *a*, *b*, *c*, and *d*. The photographs in Plate I show large inclusions uncovered at the band saw on sawing off gates from castings of No. 12 alloy. Thus, Plate I, *a*, shows a piece of brick caught in a gate cut from a crank case; in Plate I, *b*, a piece of stone in a nozzle gate; Plate I, *c*, a piece of hard clayey material in a gate from a motor housing; and in Plate I, *d*, a piece of crucible in a gate from a vacuum-cleaner casting. The magnifications given indicate the actual size of these inclusions. When such large nonmetallic inclusions occur in gates, the band saw or the sprue-cutter knife may strike them and be broken or at least dulled. If such inclusions occur in the actual castings, a cutting tool may strike them and have its edge broken off or turned over. It is more desirable that the inclusions occur in the gates than in the castings, but ordinarily if they are found in the gates they will also be found in the castings as well. However, large nonmetallic inclusions are not nearly so numerous as similar small inclusions, and the latter are likely to give more trouble on machining. Large inclusions are not likely to be numerous, but small inclusions tend to be very numerous when they are present at all.

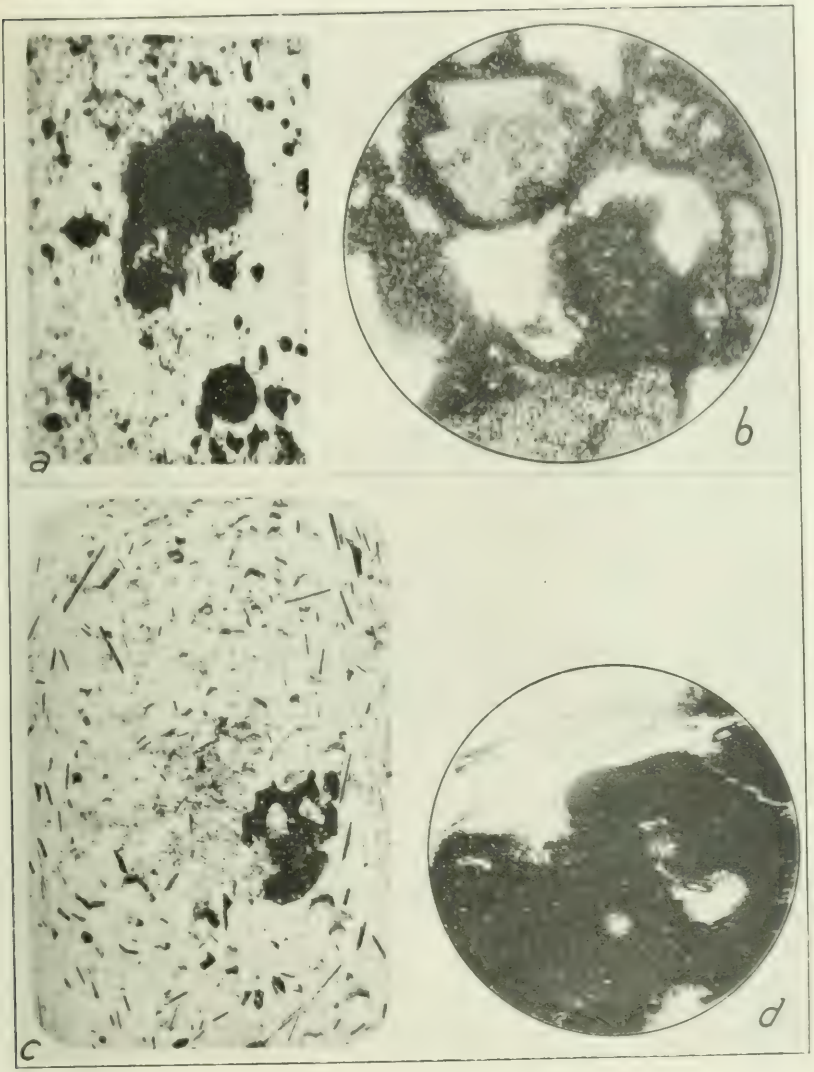
Plate II, *a*, shows some fairly large stony hard spots in a casting for vacuum-cleaner fan, and Plate II, *b*, shows some crucible bits in the same sample; the dark areas in the latter are small pieces from a plumbago-clay crucible. Plate II, *c*, shows a large piece of crucible which had been brought to the surface on polishing the casting. Plate III, *a*, is a macrograph of a section cut from a casting that gave so much trouble on machining that the casting was scrapped. The black areas in this photograph are inclusions of sand and bits of

crucible. Plate III, *b*, shows the microstructure of one of the small inclusions in Plate III, *a*. In Plate III, *c*, it shows a stony inclusion in a die casting: the large black area is the stony hard spot, and the small black needles are the iron-aluminum compound $FeAl_3$. Plate III, *d*, is a micrograph showing the structure of the stony spot; the black area is the stone, the white areas are the aluminum-alloy matrix, and the white needles are the compound $FeAl_3$.

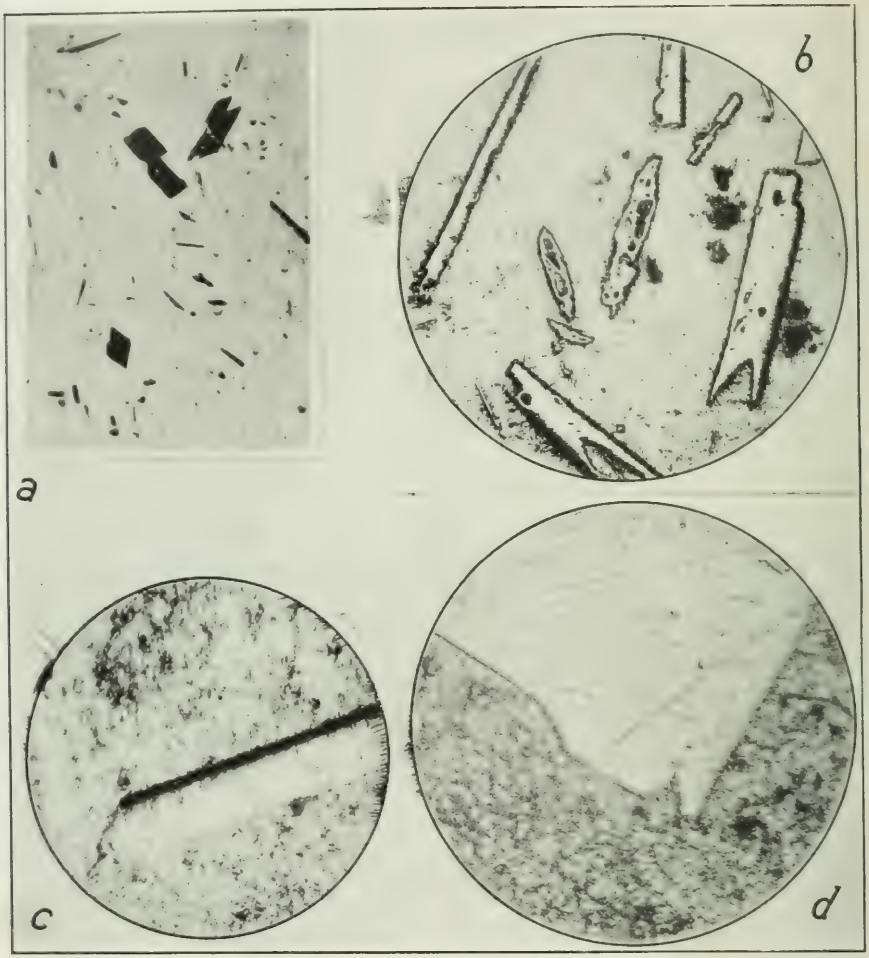
METALLIC HARD SPOTS.

So-called inclusions of the iron-aluminum compound $FeAl_3$ are not really inclusions at all; the presence of these needles of $FeAl_3$ in a 92:8 aluminum-copper alloy high in iron (say over 2 per cent), is due simply to the fact that in a ternary aluminum-copper-iron alloy $FeAl_3$ is insoluble in aluminum in the solid state. Roughly speaking, however, it may be said that so-called metallic hard spots are generally due to iron. Thus, the iron may be so high in No. 12 alloy that large crystals of $FeAl_3$, will be formed; this compound is hard and brittle, and when the iron exceeds 2 per cent, difficulty may be experienced on machining, and usually will be on polishing. Actual irony spots (true inclusions) may arise from charging nails, core wire, iron chaplets, chills, or other bits and pieces of iron with the scrap. If the melting is rapid, this iron may not dissolve completely and form $FeAl_3$, but may remain as solid iron in the liquid alloy. In the final casting, these actual pieces of iron may be shown to be steel or iron under the microscope. Moreover, if pieces of the hard iron-bearing scale formed in iron-melting pots are knocked off into the melt on stirring or ladling, actual inclusions of this scale may appear in the castings. Hence, it is advisable to distinguish clearly between so-called hard spots that are definitely known to be $FeAl_3$ and actual inclusions of iron or irony scale. The distinction can be shown readily by photomicrographs.

Plate IV, *a*, *b*, *c*, and *d*, are photographs of a section cut from an aluminum-base die casting, high in iron, which gave much difficulty both on machining and on polishing. Plate IV, *a*, is a photomicrograph showing the hard crystals and needles of $FeAl_3$ embedded in the alloy matrix. Plate IV, *b*, shows crystals of $FeAl_3$ in an unetched section at low magnification. Plate IV, *c* and *d*, show $FeAl_3$ in this same section under higher power. When a high-iron aluminum alloy is polished, the softer matrix, and the $CuAl_2$ are worn away rapidly, but the hard $FeAl_3$ is not readily worn down, and consequently stands in relief. Plate V, *a* and *b*, show aspects of the appearance of the brittle iron-pot scale when included in No. 12 alloy: Plate V, *a*, shows large inclusions of the brittle scale, and Plate V, *b*, shows the structure of the large inclusion in Plate V, *a*. The white areas in Plate V, *b*, correspond to the white specks in the inclusion in *a*; these areas are $FeAl_3$.



a, HARD SPOTS IN A CASTING THAT GAVE MUCH DIFFICULTY ON MACHINING, UNETCHED, VERTICAL ILLUMINATION (X 7); *b*, MICROSTRUCTURE OF ONE OF THE SMALL INCLUSIONS IN *a*, UNETCHED (X 100); *c*, INCLUSIONS IN A DIE CASTING (LARGE BLACK AREA, STONY HARD SPOT; SMALL BLACK NEEDLES, $FeAl_3$), ETCHED NaOH, OBLIQUE ILLUMINATION (X 8); *d*, MICROSTRUCTURE OF THE STONY SPOT IN *c* (WHITE NEEDLES, $FeAl_3$), UNETCHED (X 30).



a, CRYSTALS OF $FeAl_3$ IN A DIE CASTING THAT POLISHED POORLY, ETCHED NaOH, OBLIQUE ILLUMINATION (X 8); *b*, CRYSTALS OF $FeAl_3$ IN UNETCHED SECTIONS, FROM SAME SAMPLE AS *a* (X 30); *c*, NEEDLE OF $FeAl_3$ FROM SAME SAMPLE AS *a*, ETCHED NaOH (X 150); *d*, FEATHER OF $FeAl_3$ (WHITE) EMBEDDED IN ALLOY MATRIX (DARK), ETCHED NaOH (X 150).

CAUSES AND FACTORS AFFECTING THE OCCURRENCE OF HARD SPOTS.

The experience of foundrymen, substantiated by microscopic examination of numerous samples of castings containing hard spots, has shown that these spots may be traced to definite causes. If the causes of hard spots are eliminated, such inclusions will be absent from in the castings. Suggestions for preventing hard spots in aluminum-alloy castings will be given later in this paper (see p. 22); the causes and the factors affecting occurrence are given below.

All hard spots are doubtless due to foreign material, and there is no substantiated evidence pointing to the possibility of their being due to the original virgin-aluminum ingot or to primary alloy ingot made from virgin metals, although that possibility should not be ignored. If primary melting stock is used hard spots normally originate in the foundry or die-casting plant; if secondary aluminum ingot or secondary aluminum-alloy ingot is charged, irony hard spots may occur. (See discussion under "Causes of Metallic Hard Spots.")

CAUSES OF NONMETALLIC HARD SPOTS.

In a word, the essential cause of the occurrence of actual nonmetallic foreign inclusions in aluminum-alloy castings is the charging of foreign material into the melting furnace. New iron pots may sometimes cause hard spots because of the sand and scale adhering to them. Inclusions from this source will disappear after the pot has been in use a short time. As already stated, nonmetallic hard spots may be pieces of brick or stone, chunks of cement, pieces of crucibles, small particles of core sand and molding sand, and other extraneous substances charged into the melting pots. Such materials are likely to be numerous in foundry-floor sweepings, and nonmetallic hard spots are more likely to be present when all-scrap or high-scrap charges are run than when all-virgin melting stock is used. Moreover, surface sand holes may be formed in castings because of the erosion of molds; hard spots due to this are caused by wrong gating or too rapid pouring. Briefly, nonmetallic hard spots are normally caused by charging foreign matter into the melts, and if that is kept out of the melting furnace, it can not get into the castings.

CAUSES OF METALLIC HARD SPOTS.

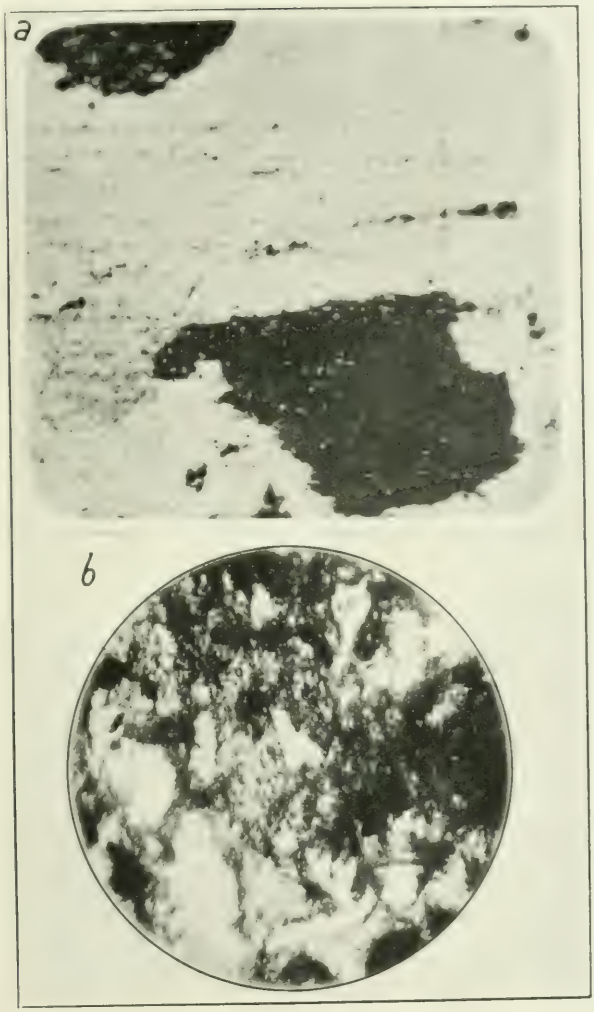
In foundry practice hard spots caused by iron may be due to four main causes: (1) The use of secondary aluminum ingot and secondary aluminum-alloy ingot, high in iron; (2) the charging of pieces of iron, such as nails, chills, core wire, steel chips, and drillings, and the like with the foundry scrap; (3) the dissolution of iron from the

pots in iron-pot melting; and (4) the hard, brittle, complex iron-aluminum alloy that forms on the sides of the iron pot. As to (1), secondary ingot can readily cause the occurrence of $FeAl_3$ spots because of the original high iron content of such ingot. Ordinarily, secondary ingot high in iron would not be employed for castings made to specifications for the automotive industry, and rarely, if ever, for vacuum-cleaner and other castings which must be highly polished. Secondary ingot should not be discriminated against, but should be analyzed. Normally, secondary ingot is not used much for die castings. However, it may cause $FeAl_3$ hard spots when used for any kind of castings if the iron content is high, say over 2 per cent.

Hard spots caused by nails, core wire, chills, and other bits of iron and steel result because this foreign metal is charged with the scrap. When actual iron or steel is charged into an aluminum-alloy melt, for example, into No. 12 alloy, the iron will go into solution in the aluminum in the liquid state if sufficient time is allowed. The rate of dissolution of solid iron in liquid aluminum is governed by time, temperature, and other factors precisely as in the solution of copper[6] in liquid aluminum. Iron forms with aluminum the iron-aluminum compound $FeAl_3$, soluble in aluminum in the liquid state, but practically insoluble in the solid state; on freezing, the $FeAl_3$ will freeze independently of the matrix in the form of needles and crystals which are hard, white, and readily identifiable under the microscope. If the iron or steel charged into the melting pots does not have sufficient time to go into solution in the aluminum, it will remain as actual iron included in the resultant castings. From the shape of the inclusions, it may be possible to determine what was the original form of the iron, a nail or a piece of core wire, for example. A machine tool or band saw designed and ground to cut an aluminum alloy will not be suitable for cutting iron; consequently, these iron inclusions appear to be, and are, much harder than the matrix of the alloy. Hard spots due to included iron are hard in the sense that iron is harder than aluminum; they are not necessarily excessively hard.

Iron dissolved from cast-iron melting pots normally forms the iron-aluminum compound $FeAl_3$. The dissolution of iron is slow under ordinary conditions of melting, and the iron content of alloys made from primary melting stock is normally low unless the heats have been held in the pot for a relatively long time and at a high temperature during melting. Metal melted in a crucible or in reverberatory-type furnaces lined with fire brick never contains

[6] Anderson, R. J., Diffusion of solid copper in liquid aluminum: Chem. and Met. Eng., vol. 23, 1920, pp. 575–577; and Preparation of light aluminum-copper casting alloys: Tech. Paper 287, Bureau of Mines (in press).



a, IRON-POT SCALE IN SAND-CAST NO. 12 ALLOY, UNETCHED VERTICAL ILLUMINATION (X 7); *b*, MICROSTRUCTURE OF THE SCALE IN *a*, $FeAl_3$ WHITE, UNETCHED (X 100).

irony hard spots unless actual iron has been charged or the iron content of the melting stock is high.

With regard to (4) above, when aluminum or its light alloys is maintained as a liquid in a cast-iron melting pot, a complex ferro-aluminum alloy is formed on the inside of the pot; this alloy adheres to the sides of the pot, but pieces of it may be knocked off into the melt upon ladling or stirring. Hard spots due to this cause do not appear when melting is done in a new iron pot because none of the hard ferro-aluminum alloy has yet formed, but when melting is done in an old pot, which has been run for a number of days without cleaning and scraping, hard spots due to this cause may be numerous in castings.

EFFECT OF SIZE OF CASTINGS.

Hard spots are presumed to be more numerous in small castings than in large ones, although there is no basis in fact for this belief, because the apparent predominance of hard spots in small castings may be explained on the ground that small castings are more generally polished than large ones. Many small die-castings and certain kinds of small sand-castings are polished, but large castings, with certain exceptions, are used in the rough except for necessary machining.

EFFECT OF MACHINING AND POLISHING.

Hard spots are said to be seldom found in the routine foundry inspection of castings, but they are revealed during machining or polishing. Hence, if a given casting requires much machining, complaints by the machine shop regarding hard spots are likely to be more numerous than in the manufacture of castings requiring but little machining. In the same way, castings which require polishing are likely to show hard spots on the polished surfaces. Complaints as to the presence of hard spots in aluminum-alloy castings usually originate in the machine shop.

EFFECT OF THE METHOD OF MOLDING.

The method of molding is a factor governing the occurrence of hard spots to a subordinate extent. Skim gates have been suggested and used in the attempt to eliminate this defect, and while they may be of some value in barring out large included particles, their use is out of the question for small castings, and they will not keep small particles out of the castings. Shrink balls and blind risers have also been suggested and used to prevent hard spots, as well as to offset excessive contraction, but these devices can not

be of any value if they are used with the idea of avoiding hard spots entirely. Their use is based on the conception that the foreign occluded matter will rise in the blind riser, but this is patently not founded on fact. Some of the occluded material is of practically the same density as the aluminum alloy, and some of it may be of greater density; such material remains more or less fixed in position in the alloy, wherever it happens to be. Blind risers can scarcely be expected to effect the removal of particles of less density than aluminum, because if these particles are not removed in the melting pot or pouring crucible, they certainly will not be eliminated by a shrink ball or blind riser.

The gating of castings is important and influences the occurrence of hard spots. Wrong gating may cause erosion of the mold on pouring. If there is a sharp constriction in a runner leading from a main gate to the casting, larger foreign particles may be trapped in the constricted area and prevented from entering the casting. On the other hand, if such a constriction is at the point where the runner joins the casting, the trapped inclusions will be frozen partly in the runner and partly in the casting; then, if machining must be done at this point on the casting, hard spots will be encountered. An examination of the method of gating and molding will assist a foundryman to determine whether any feature here may be corrected.

EFFECT OF THE METHOD OF MELTING.

The effect of the method of melting has been alluded to above in discussing the causes of hard spots. So far as is now known, it is believed that iron-pot melting presents some disadvantages which other methods do not have when considered in relation to the occurrence of hard spots. Such inclusions as are due to foreign materials being charged into the melting furnace can not be blamed upon the method of melting. However, although hard spots due to foreign materials charged may occur in any method of melting, the iron pot has the disadvantage in that iron may be dissolved and chunks of the hard ferroaluminum alloy may be knocked off into the melt. Melting in plumbago crucibles is still a fairly common practice in small foundries. If the crucibles are not used so long that they become cracked, scalped, and friable, crucible melting is satisfactory in relation to the occurrence of hard spots; but, if old, worn crucibles are employed, pieces and chunks are readily knocked off and into the melt on lifting, stirring, and pouring. Melting in open flame brick-lined furnaces or in reverberatory-type furnaces has no relation to the occurrence of hard spots, so far as is known, unless pieces of bricks are knocked off into the melt.

EFFECT OF THE QUALITY OF THE MELTING STOCK.

The effect of the quality of the melting stock has also been alluded to in discussing the causes of hard spots. Castings poured from prime virgin melting materials are less likely to contain foreign included matter or crystals of $FeAl_3$ than such castings similarly poured and melted from charges containing scrap. Normally, foundry-melting charges for No. 12 alloy are made up of virgin-aluminum ingot plus 50:50 aluminum-copper alloy and No. 12 scrap (gates, risers, defective castings, sloppings, and sweepings). Scrap of itself is not necessarily conducive to the occurrence of hard spots in the resultant castings, but the trouble arises because foreign matter is more likely to be introduced with the scrap than with virgin melting stock; hence it may be stated that the greater the percentage of scrap in the charge, the more likelihood there is that hard spots will be found in the castings. Small scrap should be charged by fork rather than by shovel, and floor sweepings should be sieved to remove particles of sand. All core sand or other adhering sand should be removed from scrap castings, which are usually charged whole, since such sand may be a prolific cause of hard spots.

EFFECT OF THE RATE OF PRODUCTION.

Generally speaking, hard spots are likely to be more predominant in castings from foundries where the production is rushed than in those where a moderate rate of production obtains, and time is allowed for careful preparation of the melting charges.

In general, carelessness tends to increase under the strain of rapid work. Although this is a minor matter it is clearly connected with the other more important factors above mentioned, and should be considered strictly in relation to them.

EXPERIMENTS IN CONNECTION WITH HARD SPOTS.

As pertaining to the present investigation, a number of experiments were made to produce hard spots in castings of No. 12 alloy at will, with the idea of attempting to ascertain the conditions which might influence the occurrence of this defect. Numerous samples of castings and gates containing actual hard spots, submitted by foundries, were also examined microscopically in order to determine the nature of these inclusions. For convenience, the main experiments relating to hard spots are referred to as foundry experiments and laboratory experiments.

FOUNDRY EXPERIMENTS.

The foundry experiments were carried out at a foundry which was having considerable trouble with hard spots in castings at the time

of the investigation. Vacuum-cleaner castings were the sole product of this foundry, and because of the design of the castings as well as the machine work and polishing subsequently done upon them, hard spots had been exceptionally prevalent. In this foundry, No. 12 alloy is used and the melting is done in covered iron pots fired by oil and in crucibles. Ordinarily the melting stock is composed of virgin aluminum ingot, plus 50 : 50 aluminum-copper alloy, plus No. 12 gates and defective castings originating in the manufacturer's plant. Foundry-casting losses were found to be reasonably low considering the specialized type of castings made, but the machine-shop scrap resulting from hard-spotted castings mounted to high figures at times. Melting, molding, core making, and supervision were good, but technical metallurgical control was not. Much of the machine-shop difficulty was determined to be in connection with machining operations on a small fan, but difficulty was experienced also from time to time when nozzles, motor housings, and bag couplings (additional cast parts used in the construction of vacuum-cleaners) were being polished. The castings were poured at 800° to 850° C., depending upon the individual job; the fans were ordinarily poured at the higher temperature because of the thinness of section. The foundry experiments were carried out with fans exclusively, but samples of the other kinds of castings were also examined for hard spots. The fan job was molded by hand from a brass pattern, six fans in a mold, and no cores were used. When the experimental sets of fans referred to below were being poured, all conditions were kept the same as far as was possible, and no other variable factors than the make-up of the melting charge and the method of melting entered into the process. In one of the experiments, however, the charge was not skimmed, and in another sal ammoniac was used as a flux. The experiments carried out in the foundry are described below.

EXPERIMENT A.

A set of vacuum-cleaner fans was poured from an all-scrap charge melted in an iron pot without skimming off the accumulated dross. This scrap charge was composed of gates and defective castings originating in the foundry and it was thought that by using all scrap and neglecting to skim, some variety of hard spots might appear in the resultant castings. As was expected, these castings were exceedingly dirty and contained much occluded dross; moreover, they were rather unsound and inclined to be porous because of the high pouring temperature. (See Pl. VI, *a*, p. 18.)

EXPERIMENT B.

Another set of fans was poured from alloy of the same heat as in experiment A, but the metal used was taken from the middle of the

pot after other castings had been poured from the top.' Moreover, the metal in the melting pot was thoroughly skimmed of all dross, and that in the pouring ladle was also carefully skimmed. (See Pl. VI, *b*; p. 18.)

EXPERIMENT C.

In this experiment, the charge consisted of all-virgin aluminum ingot plus 50:50 alloy, melted in a plumbago crucible. The crucible was carefully skimmed, and a set of fans was poured from the metal in the top of the crucible. (See Pl. VI, *c*, p. 18.)

EXPERIMENT D.

A set of fans was poured from the same charge utilized in experiment C, but the metal remaining in the bottom of the crucible, after the bulk of the alloy was poured off, was used. (See Pl. VII, *a*, p. 19.)

EXPERIMENT E.

In this experiment, the charge consisted of 50 per cent virgin aluminum ingot plus 50:50 alloy and 50 per cent gates and defective castings; the melt was made in an iron pot. The pot was carefully skimmed, and a ladleful of metal from the top was fluxed with sal ammoniac and used for pouring the castings. (See Pl. VII, *b*, p. 19.)

EXPERIMENT F.

A set of fans was poured from the same charge as that for experiment E, but metal from the bottom of the pot was used. (See Pl. VII, *c*, p. 19.)

SUMMARY OF EXPERIMENTS.

The presence of inclusions judged to be hard as shown by the fractures of the gates in experiments A to F, inclusive, together with a summary of these experiments, is shown in Table 1.

TABLE 1.—*Summary of foundry experiments: Presence of inclusions as shown by fractures of gates, and machined and polished surfaces.*

Experiment.	Method of melting.	Composition of charge.	Skimming.	Metal taken from—	Flux used.	Remarks as to appearance of fractures; 6 fractures in each case.	Rating on the basis of appearance of machined surfaces.	Rating on the basis of appearance of polished surfaces.
A	Iron pot	All gates, risers, and defective castings.	None	Top of pot	None	Many large and small inclusions in every fracture.	6	6
B	do	do	Well skimmed	Middle of pot	do	Large inclusions in 2 fractures; 4 fractures clean, much better appearance than A.	5	5
C	Plumbago crucible.	All virgin aluminum ingot plus 50:50 alloy.	do	Top of crucible	do	Small inclusions in 5 fractures; 1 fracture clean.	2	2
D	do	do	do	Bottom of crucible.	do	Small inclusions in 2 fractures; 4 fractures clean.	1	1
E	Iron pot	50 per cent gates and defective castings plus 50 per cent virgin ingot and 50:50 alloy.	do	Top of pot	Sal ammoniac.	Large and small inclusions in 3 fractures; 3 fractures clean.	4	3
F	do	do	do	Bottom of pot	None	do	3	4

EXAMINATION OF THE ROUGH CASTINGS.

A convenient foundry method for detecting the presence of hard spots before machining is to examine fractures of the gates. This procedure will avoid any unnecessary spoiling of castings. If the lead-off gate or runner from the main gate to the individual castings is constricted in area at any point, numerous inclusions (which may be hard) will be trapped at the point of constriction. Hence, when the gates are fractured or the castings simply broken off from their runners, foreign included matter may be seen in the fractures. If the hard spots are microscopic they will not be revealed at the sprue cutter or the band saw, but if large they may readily be so revealed. In the present experiments the fans were broken off from the lead-off gates, and the fractures were examined for foreign inclusions visible to the eye.

The examination of fractures of necessity may be considered only a rough foundry test indicating the presence or absence of hard spots. Despite its obvious crudity, such a test is useful indeed for that purpose.

MACHINE WORK ON THE EXPERIMENTAL CASTINGS.

Of the six castings poured in each of the experiments A to F, inclusive, three each were machined according to the regular operations called for by the job. All of the castings could have been machined, but varied somewhat in machining qualities. According to the appearance of the machined surfaces, it might be said that the castings could be rated as to machinability and freedom from hard spots in the following order: D, C, F, E, B, A. According to this rating, all-virgin materials melted in plumbago crucibles gave better results than the other melts used. While the fact is not entirely conclusive, it might be expected that crucible melting when prime materials were used would yield better castings than iron-pot melting when all-scrap or part-scrap charging materials were used. This is further corroborated by examination of polished microsections cut from the main gates in the respective experiments.

POLISHING THE CASTINGS.

Three of each set of fans cast in experiments A to F, inclusive, were polished and buffed according to usual shop practice. From visual observation the castings may be rated on appearance as follows: D, C, E, F, B, A. In other words, fewer noticeable inclusions were revealed on polishing the faces and less dragging and scratching of the polished surface by hard occluded particles was noted in the order given. Thus, with reference to the appearance of the polished

surfaces, the castings are rated in practically the same order as those examined after machining.

METALLOGRAPHY OF THE CASTINGS.

Microsections were cut from the main gates and from the actual castings of experiments A to F, inclusive, and these were examined for hard spots, general characteristics, and microstructure. Typical macrostructures of sections cut from the main gates in experiments A to F are shown in Plate VI, *a*, *b*, and *c*, and in Plate VII, *a*, *b*, and *c*. In the macrographs of Plates VI and VII the black areas may be occluded dross (hard or not hard), actual hard inclusions, or holes. Ordinarily, however, the smaller the number of black areas, the smaller the number of hard spots, irrespective of dross or holes.

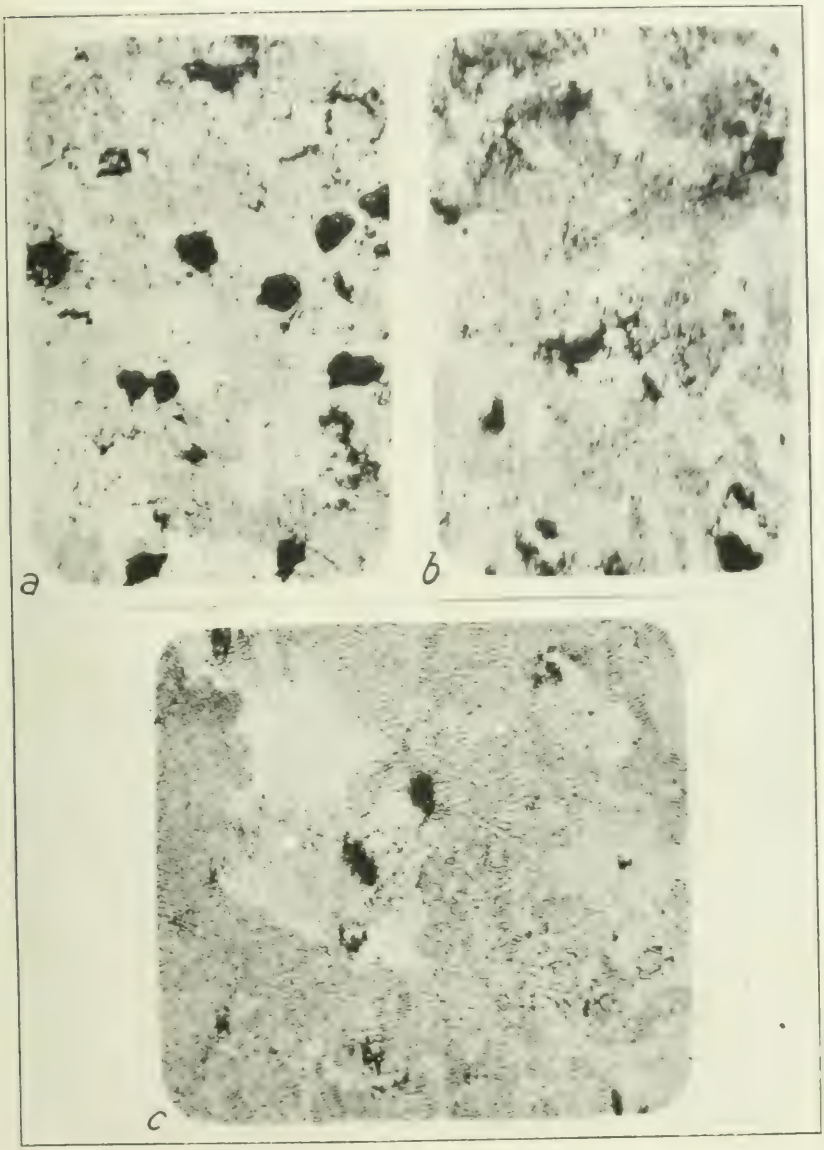
LABORATORY EXPERIMENTS.

The principal questions involved in the study of hard spots from the laboratory standpoint have been those associated with (1) the composition of iron-pot scale; (2) the composition of iron-pot scrapings; (3) the composition and identification of hard spots; and (4) the production of hard spots in aluminum alloys at will. These phases of the investigation are dealt with below.

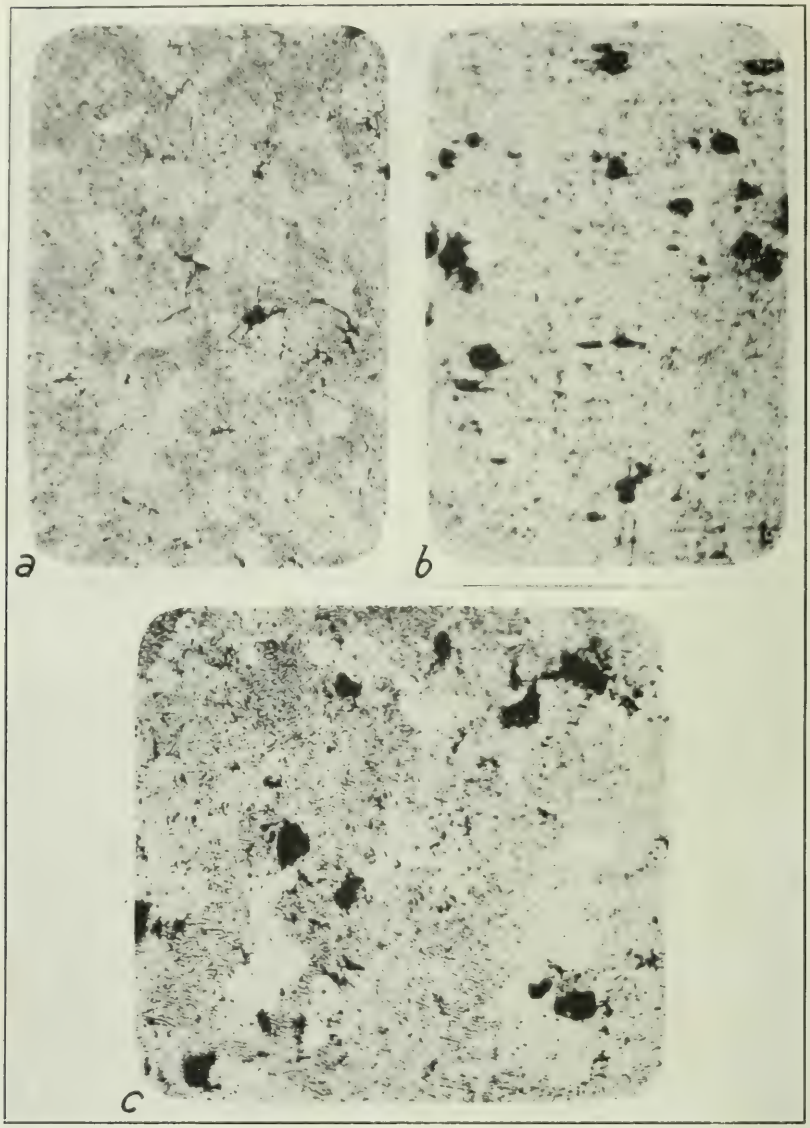
IRON-POT SCALE.

It has been claimed that hard spots due to iron-pot melting are associated with the hard complex ferro-aluminum alloy, called iron-pot scale, which forms on the sides of the pots. The statement has also been made that if this scale is scraped out thoroughly hard spots due to it can be eliminated. Furthermore, it has been claimed that the scale is readily knocked off from the side of the pot into the liquid melt, thereby causing hard inclusions.

If aluminum or one of its light alloys is kept molten in contact with cast iron, there is a gradual dissolution of iron in the aluminum and the concomitant formation of an iron rich iron-aluminum alloy on the sides of the pot. The iron content of this alloy varies throughout the section of the alloy adhering to the pot, being richest in iron in that part of the alloy adjacent to the pot and leaner in iron nearer the molten aluminum. If liquid aluminum is kept in undisturbed contact with cast iron for a long time, this iron-rich alloy gradually builds up in thickness, and it may become ¼-inch thick or thicker in the bottom of a foundry pot. This hard iron-rich alloy is not a simple binary iron-aluminum alloy, but may be rather complex, depending upon the composition of the melting pot as well as upon that of the alloy melted. In foundry practice



a. MACROSTRUCTURE OF GATE, EXPERIMENT A, ETCHED NaOH, VERTICAL ILLUMINATION (X 7); *b*. MACROSTRUCTURE OF GATE, EXPERIMENT B, ETCHED NaOH, VERTICAL ILLUMINATION (X 7); *c*. MACROSTRUCTURE OF GATE, EXPERIMENT C, ETCHED NaOH, VERTICAL ILLUMINATION (X 7).



a, MACROSTRUCTURE OF GATE, EXPERIMENT D, ETCHED NaOH, VERTICAL ILLUMINATION (X 7); *b*, MACROSTRUCTURE OF GATE, EXPERIMENT E, ETCHED NaOH, VERTICAL ILLUMINATION (X 7); *c*, MACROSTRUCTURE OF GATE, EXPERIMENT F, ETCHED NaOH, VERTICAL ILLUMINATION (X 7).

little opportunity is given for this alloy to build up to a considerable thickness on the sides of the pot near the top, because molten metal is continually being ladled out and additional cold metal charged. Any iron-aluminum alloy formed at this position in the pot may be knocked off by ladling, stirring, or charging, but in the extreme bottom of the pot conditions are different. It is normal practice in iron-pot melting to keep a molten heel of metal in the pot, and by so doing the bottom of the pot may be in direct contact with aluminum for some time. If a considerable thickness of this so-called scale has built up in the bottom of the pot or on the sides, it is quite adherent and not easily dislodged, but small accumulations are readily knocked off. Since the sides of the pot near the top are exposed both to molten aluminum and to air at elevated temperatures, the deposit which forms at this position in the pot is likely to assume the character of an iron-bearing aluminum dross, and it may be hard. The composition of some samples of iron-pot scale and of scrapings from iron pots has been determined. Table 2 gives the chemical composition of a number of samples which were analyzed. The iron content of scale scraped from the inside of melting pots is very variable, and the scale itself is a complex alloy, containing iron, aluminum, silicon, carbon, and other elements in subordinate amounts.

TABLE 2.—*Chemical composition of iron-pot scale and scrapings from iron pots.*

No. of sample.	Description of material.	Chemical composition.			
		Fe.	Si.	Al.[a]	Total C.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	Soft iron-pot scale	8.80	0.43	90.77	.....
2	Hard iron-pot scale	11.50	.....	.....	.....
3	Very soft iron-pot scale	2.46	.....	.....	.....
4	Iron-pot scrapings	1.39	.41	98.20	.....
5	....do	13.30	.....	.....	.....
6	....do	14.40	.....	.....	.....
7	....do	12.20	.....	.....	.....
8	Hard iron-pot scale	10.98	.47	86.40	2.15

[a] By difference.

THE COMPOSITION AND IDENTIFICATION OF HARD SPOTS.

Visual examination of hard spots in castings will usually give a clue to the composition of the inclusions, but microscopic examination is necessary if the inclusions are very small or if accurate determination is desired. In the foundry an approximate idea of the nature of specific inclusions can be gathered by examining fractures or machined or polished surfaces revealing hard spots, either with the naked eye or under a low-power lens. Microscopic examination is, however, more reliable and should invariably be carried out in doubt-

ful cases. The chemical composition of actual hard inclusions may only be determined with much difficulty, because it is almost impossible to separate such inclusions cleanly from the castings. Chemical analyses of large inclusions have shown them to be largely silica (chunks of stones), iron-pot scale, and pieces of plumbago-clay crucibles. Several samples of small hard spots were isolated and analyzed, but they were wetted with aluminum and consequently ran high in that element. In certain samples silicon varied from 0 to 6 per cent, aluminum from 59 to 87 per cent, and iron in subordinate amount. As a matter of fact, inclusions may be more readily identified by microscopic examination than by chemical analyses.

PRODUCTION OF HARD SPOTS AT WILL.

Numerous laboratory experiments were made to produce hard spots in No. 12 alloy at will. In the main, the attempt was made to cause the occurrence of hard spots in small melts of No. 12 alloy by stirring the following substances into the liquid alloy:

1. Core sand.
2. Silica sand.
3. Small pieces of plumbago crucible.
4. Sievings from floor sweepings.
5. Ground brick.
6. Ground cement.
7. Bits of iron nails.
8. Bits of core wire.
9. Bits of iron-pot scale.
10. Finely divided aluminum dross.

By so doing, it was possible to reproduce the conditions that are conducive to the occurrence of hard spots in the foundry, and these experiments have served usefully to corroborate conclusions drawn from the examination of actual hard spots in castings. The above experiments are of such an elementary character that no detailed account is deemed necessary.

SUMMARY AND CONCLUSIONS.

In considering the effect of the occurrence of so-called hard spots in aluminum-alloy castings upon casting losses in foundry practice, it is advisable to recall that a not inconsiderable percentage of the castings returned from the machine shop may be rejected because of this defect. Any constructive code of rules that will apply to foundry practice, looking to the prevention of hard spots in castings, should be of value to foundrymen and materially assist in reducing losses of all kinds which are caused by this defect. The problem is one which is mainly the concern of individual foundries, and their profits irrespective of its broader economic aspect. Since it has been

impossible to obtain figures as to the monetary losses occasioned by this difficulty, no estimates can be made of the actual losses of the country. Sufficient evidence is available, however, to indicate that the losses are sufficiently serious to require the careful attention of all foundries, and that steps should be taken to reduce them to a minimum by applying constructive measures in each foundry. Based upon the experience of the numerous foundrymen who have cooperated in this investigation, and upon the results of the study, it is apparent that careful attention to certain aspects of foundry practice may substantially prevent the occurrence of hard spots, which give difficulty on machining. Suggested methods are discussed briefly below.

METHODS OF PREVENTING HARD SPOTS.

Hard spots due to foreign matter other than iron originate in the foundry and can be prevented by not allowing such materials to get into the melting furnace. When the melting room and foundry floor are being cleaned to gather up small pieces of metal, sloppings, overruns, and the like, dirt, gravel, sand, cement, pieces of brick, and chunks of broken crucibles, etc., are swept up. Unless these floor sweepings are sieved and forked, such foreign materials are likely to be charged into the melting furnace. The presence of foreign materials in the melting charge can be largely eliminated by carefully watching what goes into the furnaces. Carelessness is the main cause of the presence of such foreign materials, but under the conditions brought about by fast practice, the requisite care can not always be given. However, whether under fast practice or a moderate rate of production, it will pay to watch the quality of the melting charge.

All small foundry scrap should be forked before charging, and floor sweepings should be sieved. Some of the foreign material which is inadvertently charged into the furnace may be removed by skimming and fluxing, but it is not safe to rely upon these practices to overcome the evils of a dirty charge. If the admixed foreign matter is readily wetted by aluminum, and is of nearly the same density as the metal, or both, it will remain in the liquid metal and ultimately appear in the castings. In crucible melting, particularly where the crucibles are old, badly cracked, and weak, pieces of the crucible may fall or be knocked into the metal and carried into the castings. Where plumbago crucibles are used for pouring with any kind of melting practice, pieces of the crucible may be found in the castings, hence crucibles should not be used too long or until they become cracked and readily friable. No core sand should be left in defective castings that are remelted, as the hard, fine, silica

particles may give rise to small hard spots. Foreign nonmet hard spots can be largely eliminated, provided sufficient atten is given to the charging practice.

The status of conditions occasioning hard spots caused dire or indirectly by iron has already been explained at some length. iron content of No. 12 alloy or other alloys made from secon ingot can be kept within reasonable limits by using only such i as is reasonably low in iron. Difficulties brought about by the of secondary ingot, or scrap castings purchased from outside sou can be readily eliminated by chemical analytical control. Ac irony hard spots caused by charging nails, core wire, chills, and of iron and steel can be prevented by careful attention to the qua of the charge. Mechanically admixed iron appearing in the foun scrap or in floor sweepings can be removed by screening and fork or by electromagnetic apparatus if required. If small loose sc is charged by fork rather than by shovel, small particles of iro nonmetallic particles should readily fall between the tines of a f whereas they would be retained by the shovel and go into the cha However, if too much scrap is picked up on the fork, the small pi will not fall through and forking does no good. Unless small fo ful of scrap are taken and the scrap shaken up and down on the f forking is useless. In certain foundries, forks are used like shov but if they are not used correctly they may as well not be used at The practice of charging borings and turnings has practically b abandoned, and these are usually run down into ingots before cha ing. However, in a machine shop iron and steel drillings and tu ings may become admixed with aluminum-alloy borings. If t happens and such borings are charged directly hard spots due to i may appear in the resultant castings. Unless it is known t aluminum-alloy borings are free from mechanically admixed ir they should not ordinarily be charged directly. At best it is good practice to use borings in melting charges because of hea dross losses.

Hard spots due to the brittle, complex, ferro-aluminum alloy wh forms on the sides of iron pots may be largely prevented by th oughly scraping the pots at frequent intervals and removing t accumulated scale. If eight or nine hour practice obtains, the p should be scraped at least once a day, say at night, and preferal twice a day, at noon and night. If two shifts are working, m frequent scrapings will be advisable. All of the hard alloy shou be removed so that the pot is clean, and if necessary the pot shou be dumped. Moreover, during the time the pot is in melting ope tion, care should be taken that ladles or stirrers do not hit the si of the pot; otherwise, some of the accumulated scale may be knock off. In the same way, the scale may be dislodged at charging ti

By careful attention to the foregoing items, the occurrence of [illegible] pots in aluminum-alloy castings that give rise to difficulty [illegible] hining and polishing can be largely eliminated.

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particles may give rise to small hard spots. Foreign nonmetallic hard spots can be largely eliminated, provided sufficient attention is given to the charging practice.

The status of conditions occasioning hard spots caused directly or indirectly by iron has already been explained at some length. The iron content of No. 12 alloy or other alloys made from secondary ingot can be kept within reasonable limits by using only such ingot as is reasonably low in iron. Difficulties brought about by the use of secondary ingot, or scrap castings purchased from outside sources, can be readily eliminated by chemical analytical control. Actual irony hard spots caused by charging nails, core wire, chills, and bits of iron and steel can be prevented by careful attention to the quality of the charge. Mechanically admixed iron appearing in the foundry scrap or in floor sweepings can be removed by screening and forking, or by electromagnetic apparatus if required. If small loose scrap is charged by fork rather than by shovel, small particles of iron or nonmetallic particles should readily fall between the tines of a fork, whereas they would be retained by the shovel and go into the charge. However, if too much scrap is picked up on the fork, the small pieces will not fall through and forking does no good. Unless small forksful of scrap are taken and the scrap shaken up and down on the fork, forking is useless. In certain foundries, forks are used like shovels, but if they are not used correctly they may as well not be used at all. The practice of charging borings and turnings has practically been abandoned, and these are usually run down into ingots before charging. However, in a machine shop iron and steel drillings and turnings may become admixed with aluminum-alloy borings. If this happens and such borings are charged directly hard spots due to iron may appear in the resultant castings. Unless it is known that aluminum-alloy borings are free from mechanically admixed iron, they should not ordinarily be charged directly. At best it is not good practice to use borings in melting charges because of heavy dross losses.

Hard spots due to the brittle, complex, ferro-aluminum alloy which forms on the sides of iron pots may be largely prevented by thoroughly scraping the pots at frequent intervals and removing the accumulated scale. If eight or nine hour practice obtains, the pots should be scraped at least once a day, say at night, and preferably twice a day, at noon and night. If two shifts are working, more frequent scrapings will be advisable. All of the hard alloy should be removed so that the pot is clean, and if necessary the pot should be dumped. Moreover, during the time the pot is in melting operation, care should be taken that ladles or stirrers do not hit the sides of the pot; otherwise, some of the accumulated scale may be knocked off. In the same way, the scale may be dislodged at charging time.

By careful attention to the foregoing items, the occurrence of hard spots in aluminum-alloy castings that give rise to difficulty on machining and polishing can be largely eliminated.

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